Impact of an Abdominal Binder on Speech Outcomes in People With Tetraplegic Spinal Cord Injury: Perceptual and Acoustic Measures

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Background: An abdominal binder (AB) is routinely used for patients who have suffered a spinal cord injury (SCI) resulting in tetraplegia. It is thought to restore abdominal pressure and consequently improve breathing capacity and reduce postural hypotension in patients who do not have functioning abdominal muscles. **Objective:** To examine the early effects of an AB on respiratory and speech outcomes. **Methods:** Thirteen individuals who sustained an acute motor complete SCI between C3 and T1 were assessed after a 6-week trial of using an elasticized AB from the time of first mobilizing in an upright wheelchair. Assessments were made using spirometry and perceptual and acoustics speech measures based on sustained phonation, sentence recitation, and passage reading. **Results:** Significant improvements were found in the AB-on condition for 3 of 5 respiratory parameters (vital capacity, forced vital capacity, and forced expiratory volume in 1 second). Predominantly mild voice and speech dysfunction were noted in participants. No significant difference was found for any of the acoustic and perceptual speech parameters (maximum phonation time, vocal intensity for sentence recitation, perceptual speech characteristics, or vocal quality) between the AB conditions. **Conclusions:** Despite the finding that an AB results in significant improvements in respiratory function for individuals with tetraplegic SCI, the current study did not provide evidence that an AB improves speech production. **Key words:** abdominal binding, lung function, speech, spinal cord injury, voice

Respiratory dysfunction as a result of weakened or paralyzed respiratory muscles is a well-documented consequence of spinal cord injury (SCI) and a major cause of morbidity and mortality.¹ Neuromuscular impairment of the respiratory muscles in SCI impacts inspiration and expiration,² with lesion level and completeness related directly to the amount of dysfunction. Higher lesions lead to greater respiratory compromise. Unlike lesions above C4, those at C4 level and below allow for at least partial diaphragmatic function, but respiratory function can still be considerably impaired. Respiratory dysfunction arises due to impairment of the intercostal muscles (innervated

by thoracic nerves arising from T1-12), abdominal muscles (innervated from nerves arising from T6-12), and to a lesser extent accessory muscles (innervated by spinal nerves arising from C1-7).³ The majority of individuals with SCI below C4 are able to breathe independently, but paralysis of the intercostal muscles together with abdominal muscle weakness can result in reduced and/or paradoxical chest wall motion, reduced inspiratory function, and decreased active expiratory forces.^{4,5}

Respiratory dysfunction in SCI leads to reduced pulmonary capacity, hypersecretions, ineffective cough, and accumulation of airway secretions⁶ due to an individual's inability to inhale deeply and expire forcefully.⁵ Reductions in pulmonary

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function have been documented to include decreased total lung capacity (60%-80% of predicted value),⁷ reduced vital capacity (50%-80% of predicted value),^{8,9} reduced inspiratory and expiratory pressure and capacity,^{10,11} and increased residual volumes.⁷ Reduced respiratory function also has the potential to affect speech, as the respiratory system is the driving force that generates air flow for speech production.¹² Reported perceptual speech deficits have been grouped into 3 clusters: impaired breath support, deviations in vocal quality, and atypical prosodic characteristics.¹³⁻¹⁶ Characteristics such as short phrases, slow and shallow inspirations, reduced vocal loudness, vocal quality disturbances (eg, harshness, breathiness, strain), and impaired prosody of speech (eg, reduced pitch and loudness variation, altered rate and rhythm of speech)^{4,13,16} have been observed in individuals with SCI.

A recent interview study of 33 participants that sought to understand how reduced lung function affects individuals with high SCI (C4 to C8 level injuries) reported 3 areas of limitations, 1 of which was voice function.¹⁷ Vocal function limitations identified were related to poor vocal endurance and vocal strength; this was most notable in social situations. The group appeared to see these limitations as part of normal life post SCI; self-management included compensatory strategies, education of communication partners, and use of specific breathing and speech techniques. Despite individuals with SCI and professionals identifying changes in speech production following high SCI, there has been limited research into effective and efficacious treatments.

Treatment options to address the effects of respiratory insufficiency post SCI on speech may utilize either a behavioral or prosthetic approach.^{4,18,19} Behavioral approaches include resistance training of respiratory muscles,²⁰ endurance training of inspiratory muscles,²¹ or glossopharyngeal breathing (GPB).^{14,22,23} Of these behavioral approaches, GPB is the only one that has demonstrated a positive effect on speech production by increasing vital capacity, which in turn results in increased vocal loudness, utterance length, and phonatory stability. Speech comprehensibility and naturalness, however,

have been acknowledged as being potentially compromised in GPB. This may limit GPB's acceptability and suitability to all individuals with SCI who experience impaired speech function. An additional limitation to its clinical applicability may be that it is a difficult breathing technique to master and requires considerable practice and motivation.²⁴

Prosthetic procedures offer another treatment option by enhancing postural support during respiration; these can be used in isolation or conjunction with behavioral techniques. The benefits of prosthetic approaches, such as binding of the paralyzed abdomen to improve respiratory function for speech, have been documented in case study reports of individuals with chronic SCI.^{12,25} Abdominal trussing has been reported to improve both inspiratory capacity and vital capacity leading to greater ease in speaking, longer utterances, and listener preference for speech produced with the support of trussing.¹² Substantial evidence also supports an abdominal binder (AB) as a means of optimizing respiratory function along with managing early orthostatic hypotension,²⁶ increasing vital capacity,^{27,28} improving total lung capacity and inspiratory capacity,^{26,29} and increasing expiratory volumes and flow.^{28,29} Self-report by individuals with SCI wearing an AB has revealed a perceived benefit in terms of breathing, cough, and general respiratory effort.^{29,30} It could therefore be suggested that an AB has the potential to improve speech production in people with high SCI because it improves respiratory function. Previous case study reports of 2 individuals with chronic high SCI using phrenic nerve pacers have provided preliminary support for the beneficial effects of an AB on speech production in addition to increased tidal volumes.²⁵ Specifically, listener preference for speech samples produced while the speaker was wearing the AB was noted, as was increased vocal loudness in one participant. In a recent study of 14 individuals with high SCI less than 12 months post injury, vocal intensity (as measured acoustically) was not improved by the wearing of the AB, but improvements in maximum phonation time were observed.²⁸ These studies highlight the potential for an

AB to improve respiratory function for speech and therefore speech production, but further investigation is needed before recommendations can be made about the use of an AB as a speech rehabilitation option for people with high SCI.

Although the behavioral and prosthetic approaches have been shown to have potential as management techniques that could address speech production deficits caused by respiratory dysfunction, comprehensive studies with greater methodological rigor are needed to establish the physiologic, acoustic, and perceptual speech changes associated with these management approaches. The present study aims to determine the effect of an AB on the acoustic and perceptual characteristics of speech production in individuals with high SCI. It is hypothesized that high SCI patients will experience enhanced pulmonary function when wearing an AB that would result in improved speech production as compared to when not wearing an AB.

Method

The study was conducted at an adult spinal injuries unit (SIU) at a major tertiary university hospital in Brisbane, Australia (January 2008 to October 2009). Ethical clearance was provided through the local human research ethics committees.

Participants

Participants were individuals who had sustained an acute traumatic SCI with motor complete (A or B) neurological impairment above T5 according to the American Spinal Injury Association Impairment Scale (AIS),³¹ were age 18 years or older, and were English speaking. At the time of inclusion, participants had to be capable of sitting upright in a wheelchair, able to wear an AB during waking hours, show no signs of diaphragm paralysis, and provide informed consent. Potential participants were excluded if they had a stage 2 or above pressure area in the region of the AB that would prevent its application, a traumatic brain injury, and/or active respiratory disease.

The group was predominantly male ($N = 12$), with a mean age of 36.9 ± 21.8 years (range, 18–82) and site of lesion ranging from C3 to T1 with primarily C4 and C5 injury ($n = 10$). At the time of data collection, all participants were wearing the AB on a daily basis when sitting upright in their wheelchair as per standard practice for management of orthostatic hypotension. The elasticized AB (Medical Accessories of Australia, Milton, Queensland, Australia) was made of polyester and 20% spandex. This AB is available in several widths and lengths and was fitted to the individual so as to provide firm support around the abdomen from the anterior superior iliac crest to the costal margin of the rib cage.

Measures

Respiratory measures

A handheld SpiroPro spirometer (CareFusion Switzerland, Rolle, Switzerland) was used to measure vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), and peak expiratory flow (PEF). Maximum expiratory pressure (MEP) was measured using the MicroRPM (CareFusion) handheld respiratory pressure meter with a tube-style mouthpiece. Definitions and procedures followed for each of the respiratory measurements are provided in **Table 1**. During spirometric recordings, participants were required to maintain adequate lip seal around the spirometer's mouthpiece and wear a nose clip to prevent nasal air escape. Performance on each task was compared to known predicted values for sex, age, and height according to published reference values.³²

American Thoracic Society/European Respiratory Society (ATS/ERS) spirometry standard guidelines³³ were followed when the respiratory function tests were conducted and, where necessary, were modified to incorporate the limitations associated with SCI.^{26,27} When spirometry data obtained from participants satisfied spirometry acceptability but did not meet repeatability criteria, their best acceptable curve was used in statistical analyses, as per ATS/ERS guidelines. Participants were allowed up to 8 attempts to achieve repeatability criteria.

Table 1. Description of the respiratory parameters

Parameters	Description	Procedure
Vital capacity (VC)	Maximum amount of air a person can expel from the lungs after a maximum inspiration	The participant was asked to take a deep breath, inspiring fully from the resting expiratory level, and then completely empty their lungs by expiring fully into the spirometer.
Forced vital capacity (FVC)	Volume change of the lung between a full inspiration to total lung capacity and a maximal expiration to residual volume	FVC, FEV ₁ , and PEFr were calculated from the following respiratory maneuver: The participant was instructed to take in a normal-sized breath and breathe out all of the air in his or her lungs, then take in a large breath to fill his or her lungs completely and then expel the air out maximally while sustaining this effort for at least 6 seconds or longer if possible.
Forced expiratory volume in 1 second (FEV ₁)	Volume exhaled during the first second of a forced expiratory maneuver started from the level of total lung capacity	
Peak expiratory flow rate (PEFR)	Maximum flow generated during expiration performed with maximal force and started after a full inspiration	
Maximum expiratory pressure (MEP)	Greatest mouth pressure of expired air achieved by a person after a full inspiration	The participant was instructed to use maximal effort to breathe in and when he or she had reached the maximum inspiration point (ie, total lung capacity) to use maximal effort to expire all of the air and maintain for at least 1 second. Note: Training was provided for this task.

Speech measures

A number of speech tasks were audio-recorded using a portable digital MP3/Wave recorder (Edirol R-1, Roland) for later perceptual and acoustic analysis. A headset microphone (AKG Model C420) was positioned at a mouth-to-microphone distance of 5 cm during recordings. Speech samples were recorded as digital .wav files at a sampling rate of 44.1 kHz with 16-bit quantization. Speech-like and speech tasks included (a) maximum phonation time, (b) sentence repetition at 2 loudness levels (normal and loud), and (c) oral reading of The Rainbow Passage.³⁴ All tasks, with the exception of the oral reading task, were repeated 3 times after an example was provided by the assessor; the reading task was completed once.

Maximum phonation time (MPT) was measured as the maximum length of time a participant could sustain the sound “ah” with even pitch

after a large inhalation. Standardized instructions were provided to participants: “Take in the deepest breath possible and then produce the sound ‘ah’ for as long as you can until you have used all your air.” The examiner provided an example and training as required to ensure compliance with the task. Vocal intensity, as measured by sound pressure levels, was based on recitation of the sentence “Combine all the ingredients in a large bowl” at a conversational speech level and maximal vocal loudness. Mean sound pressure level (SPL) across the sentence was calculated and used for statistical analyses. Standard instructions and a demonstration were provided to each participant, and each task was repeated 3 times. The oral reading of The Rainbow Passage was utilized for perceptual speech analysis, and participants were given time to familiarize themselves with the content of the passage. When they were ready, they read the passage aloud in a comfortable voice.

Data collection procedure

Spirometric, perceptual, and acoustic speech measures were collected 6 weeks after the participants had commenced daily wheelchair use and wearing an AB. Data were collected under 2 conditions: (1) AB-on and (2) AB-off. The order of the testing condition was randomized across the group using a computer-generated random numbers list to control for order effect. The assessor was not blinded to the application of the AB, but data were coded such that researchers completing the analyses were blinded to condition. Total assessment time was about 2 hours for each individual, with a minimum of 5 minutes between conditions to allow the participant to rest. For application of the AB, participants were positioned in supine to ensure adequate compression of the soft tissue over the abdomen on end expiration, aiming to reduce seated girth by approximately 10% (see Kerk and colleagues for details³⁵).

Speech analysis procedures

Acoustic analysis of the speech samples was conducted using the multidimensional voice program (MDVP) or real-time pitch program on the Computerized Speech Lab (CSL model 4500, KayPentax).³⁶ Visual and auditory inspection of sound files was conducted prior to analysis to ensure the integrity of the samples. Maximum phonation time was calculated in seconds using the CSL, with the average of the 3 trials used for statistical analysis. Visual and auditory inspection of the sound files was used to identify the onset and offset of phonation; cursors were placed at these points and phonation time was generated automatically. Trials of the sentence recitation task for both loudness levels (3 repetitions each) were digitalized by the CSL. Auditory and visual examination of the acoustic files was conducted to determine the onset and offset of the sentence, with the analysis cursors placed at the beginning and end of the sentence using the real-time pitch program of the CSL. The real-time pitch program automatically generated a range of pitch and energy values, with the average sound pressure level measured in decibels (dB) recorded from each of the sentences trials.

MPT sound files were used to complete an acoustic analysis of voice using MDVP. All 3 productions of the vowel /a/ were digitalized by the CSL; a 2-second sample was taken from the mid-portion of the vowel for analysis so as to avoid the initial and terminal portions of phonation that can be sensitive to vocal variations and alter the results.³⁷ Eight MDVP measures were used in the current investigation, because they have been identified in the literature³⁸ as relating to the perceptual parameters of the GRBAS scale.³⁹ The parameters utilized were (a) frequency perturbation measurements – percent jitter (Jitt), pitch period perturbation quotient (PPQ), and fundamental frequency variation (vFo); (b) amplitude perturbation measurements – percent shimmer (Shimm) and amplitude perturbation quotient (APQ); and (c) noise and tremor evaluation measurements – noise-to-harmonic ratio (NHR), voice turbulence index (VTI), and soft phonation index (SPI).

Perceptual speech sample analysis was conducted at 2 levels: (1) vocal quality analysis using the GRBAS scale,³⁹ and (2) comparative analysis of paired speech samples. Vocal quality analysis for each speech sample was analyzed by a speech pathologist using the GRBAS scale, which consists of 5 parameters: grade (G), roughness (R), breathiness (B), asthenicity (A), and strain (S). These parameters were rated on a 4-point scale (0 = *normal*, 1 = *mild*, 2 = *moderate*, and 3 = *severe*). All oral reading samples (AB-on and AB-off conditions) from the 13 participants were randomized and recorded to disc for GRBAS analysis. Comparison mean opinion score (CMOS)⁴⁰ analysis was used to compare the paired audio recordings of the reading task across a number of perceptual features. Judgments of the paired samples were made on the parameters of ease of the understanding, perceived vocal effort, loudness level, speech naturalness, and overall voice quality. The samples were de-identified and saved as paired samples (AB-on and AB-off) for each participant; randomization was used to vary the presentation order of the 2 samples across participants. These paired samples were then rated by a speech pathologist using the CMOS process. Sample 1 and sample 2 were presented, then the clinician was required to rate sample 2

Table 2. Comparison of respiratory functions: AB-off versus AB-on condition

Respiratory variables	AB-off condition		AB-on condition		<i>t</i>	<i>P</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
VC (liters)	2.38	0.47	2.69	0.45	26.30	<.01*
FVC (liters)	2.51	0.51	2.80	0.58	19.47	<.01*
FEV ₁ (liters)	1.90	0.41	2.10	0.43	9.11	.01*
PEF (L/s)	3.59	1.12	4.12	1.16	4.96	.05
MEP ^a (cmH ₂ O)	32.67	8.32	34.78	8.94	1.28	.24

Note: AB = abdominal binder; FVC = functional vital capacity; FEV₁ = functional expiratory volume in one second; PEF = peak expiratory flow; MEP = maximum expiratory pressure.

^aData are missing for 4 participants due to unavailability of equipment.

*Significant result $P \leq .05$.

in relation to sample 1 on a scale of -3 to +3, in which 0 indicated the samples were equal on the perceptual characteristic. If the value was negative, it indicated that sample 2 was worse than sample 1 (-1 = *slightly worse*; -2 = *worse*; -3 = *much worse*), whereas a positive value indicated that sample 2 was better than sample 1.

Statistical analysis

Paired *t* tests were used for the spirometric and acoustic variables to determine whether there was a significant difference between the AB-on and AB-off conditions. Results attained from the GRBAS scale analysis were analyzed using the Wilcoxon signed rank test, whereas CMOS analysis was described using frequency counts to report presence or absence of change in perceptual characteristics. All statistical analyses were performed using STATA version 10. A significance level of $P < .05$ was used to establish statistical difference.

Results

Respiratory measures

Significant improvements were observed in 3 of the measured respiratory parameters (VC,

FVC, and FEV₁) when they were compared across AB conditions (see **Table 2**). Average group improvement was greater than 10% across 4 measures including 13% for vital capacity, 12% for forced vital capacity, 11% for FEV₁, and 15% for PEF.

Speech measures

No significant difference was found between AB conditions for MPT ($M^{\text{AB-off}} = 8.9 \pm 3.3$; $M^{\text{AB-on}} = 9.8 \pm 3.7$), vocal intensity at normal conversation level ($M^{\text{AB-off}} = 57.3 \pm 3.4$; $M^{\text{AB-on}} = 57.7 \pm 3.8$), or vocal intensity at loud conversation level ($M^{\text{AB-off}} = 65.49 \pm 5.2$; $M^{\text{AB-on}} = 66.6 \pm 5.7$). Analysis also revealed no significant difference between AB conditions for any of the 8 MDVP parameters collected. An average 10% increase in MPT for participants in the AB-on condition when compared to AB-off was of clinical significance.

The GRBAS ratings revealed that there was no significant change in the overall rating of vocal quality (grade) across conditions; in general, where participants experienced a deviance in vocal quality, it was only mildly impaired (median = 0; range, 0-2). Similarly, there was no significant difference for each of the deviant vocal qualities scored by the GRBAS (roughness, breathiness, asthenicity, strain) across the AB conditions.

At a group level, CMOS analysis revealed that 3 parameters (speech naturalness, vocal loudness, and overall vocal quality) had at least 30% of participants with superior ratings when wearing the AB. Six of the participants (participants 1, 2, 3, 4, 5, and 7) produced more natural sounding speech during the AB-on condition, whereas the speech samples of 4 participants were perceived to have increased vocal loudness (participants 2, 5, 11, and 15) and improved overall voice quality (participants 1, 5, 9, and 13) when wearing the AB. Furthermore, 2 participants demonstrated consistent benefits across more than 2 parameters. Participant 5 showed improvement in naturalness, loudness, and overall voice quality, whereas participant 1 exhibited better performance in naturalness, roughness, and overall voice quality.

Discussion

Results from the current study support previous findings that wearing an AB has a positive effect on respiratory function, with statistically significant improvements in VC, FVC, and FEV₁. However, improvements in respiratory function did not result in overall significant improvements in perceptual voice or acoustic speech outcomes in this group. Despite the absence of statistically significant results for many of the speech outcomes measures, perceptual speech characteristics such as speech naturalness, vocal loudness, and overall quality were perceived to be superior for at least one-third of the participants when wearing the AB. Although the positive benefits of AB on some respiratory function measures were replicated in our study, the findings are still equivocal in terms of AB's benefits to speech production.

Respiratory function

Improvements in respiratory function seen in our participants, as measured by VC, FVC, and FEV₁, were consistent with the majority of previous studies evaluating the effect of an AB on such measures. Magnitude of improvement in VC achieved in the AB-on condition for the current group was an average of 13% as compared

to AB-off. It was comparable to previous reports by Goldman et al²⁷ at 11.5% and Bodin, Fagevik Olsen, Bake, and Kreuter⁴¹ at 10% in patients with complete C5-C8 lesions. Clinical improvements in FVC, FEV₁, and PEF observed in the AB-on condition were also in accordance with findings reported by Hart et al²⁹ in 10 participants with C5 to T6 SCI. The mechanism of this improvement is thought to result from AB creating a more stable abdomen through which to generate pressure to the thorax and thus enhance inspiratory/expiratory muscle activation on the rib cage.⁴²

Acoustic and perceptual speech outcomes

Maximum phonation tasks are considered to be closely related to respiratory function, however the improvements in respiratory function associated with wearing the AB in the current study did not translate to significant improvements in MPT. Similarly, vocal intensity during sentence recitation (perceived as vocal loudness) at both conversational and loud levels was not found to benefit significantly from the wearing of an AB in the current study. These findings appear to contrast with the findings of Hoit et al.²⁵ It should be noted that the individual cases reported by Hoit and colleagues used AB in the presence of phrenic nerve pacing for diaphragm paralysis. Contrasting the group findings, individual paired comparisons of perceptual speech characteristics using CMOS ratings revealed increased loudness on an oral reading task for 4 participants when wearing the AB, comparing favorably with Hoit and colleagues'²⁵ earlier findings. Additionally, speech naturalness was enhanced for just under half of the participants when wearing an AB. This is in keeping with previous case study investigations that have shown positive outcomes in relation to speech naturalness or listener preference, length of utterance, and ease of speaking.^{12,25} Although increased lung volumes may contribute in some form to improved speech naturalness, greater efficiency in the inspiratory phase through optimization of the diaphragm position may be the key, as suggested by Watson and Hixon.¹²

Generally the participants presented with no to minimal changes in vocal quality. Therefore, the absence of a significant change in either the MDVP acoustic voice parameters or the perceptual voice characteristics of the GRBAS is perhaps not surprising. Although changes in voice quality are well documented in people with SCI,¹³⁻¹⁶ the absence of voice dysfunction in the current study may represent differences between the populations studied in terms of time post injury, site of lesion, and potentially the absence of laryngeal dysfunction.

Strengths, limitations, and future directions

The current research is the first cohort study to investigate the effect of an AB on speech and voice function; it expanded on previous literature regarding the positive benefits of binding the abdomen on pulmonary function. A number of study limitations need to be acknowledged. Although it is the largest to date, the study was most likely underpowered as the sample was relatively small and had large variability on some measures. Furthermore, the participants in the current study presented with predominantly mild speech deficits; this may have influenced our ability to detect improvements. An AB may be more effective for individuals with more severe speech and voice deficits; therefore, a future study including participants with SCI with varying levels of speech impairment is required. A limitation around the perceptual speech data analysis procedures was the use of a single rater for the GRBAS and CMOS scales. It is recommended that future studies use a group of listeners to rate perceptual speech and voice characteristics. Timing of the intervention may also have influenced the findings. Study participants were tested early post injury (6 weeks after participants first sat upright and mobilized in a wheelchair); their muscle compliance was still changing, and the effect of the AB on speech

production may vary at times further post injury. Additionally, the participants in the current study were not provided with any breathing techniques or behavioral speech therapy to utilize the improved respiratory function gained from the AB. Future studies should include a comparison group that uses both an AB and behavioral therapy aimed at maximizing increased respiratory function for speech production. Additionally individuals with SCI should be asked about the perceived benefits to their speech and breathing from wearing an AB to add to our understanding of the benefits of this type of intervention.

Conclusion

Although some individual benefits were noted, the current study did not provide evidence that an AB improves speech production in individuals with respiratory dysfunction associated with high SCI, despite significant changes in respiratory function. Further research with larger and more varied participant samples is required to determine whether there are areas of speech production that can benefit from an AB. This may determine for whom it is most effective and whether gains in respiratory function through wearing an AB can be maximized by combining its use with behavioral therapy approaches.

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REFERENCES

- DeVivo MJ, Krause JS, Lammertse DP. Recent trends in mortality and causes of death among persons with spinal cord injury. *Arch Phys Med Rehabil*. 1999;80(11):1411-1419.
- Boone DR, McFarlane SC. *The Voice and Voice Therapy* (6th ed.). Boston: Allyn and Bacon; 2000.
- Zejdlik CP. *Management of Spinal Cord Injury*. Boston: Jones and Bartlett; 1992.
- Hixon TJ, Hoit JD. *Evaluation and Management of Speech Breathing Disorders*. Tuscon: Reddington Brown LLC; 2005.
- Brown R, Di Marco A, Hoit JD, Garshick E. Respiratory dysfunction and management in spinal cord injury. *Respir Care*. 2006;51(8):853-868.
- De Troyer A, Estenne M. Review article: The expiratory muscles in tetraplegia. *Paraplegia*. 1991;29:359-363.
- Estenne M, Muylem AV, Gorini M, Kinnear W, Heilporn A, Troyer AD. Effects of abdominal strapping on forced expiration in tetraplegic patients. *Am J Respir Crit Care Med*. 1998;157:95-98.
- Anke A, Aksnes A, Stanghelle J, Hjeltnes N. Lung volumes in tetraplegic patients according to cervical spinal cord injury level. *Scand J Rehabil Med*. 1993;25:73-77.
- Jain N, Brown R, Tun C, Gagnon D, Garshick E. Determinants of forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and FEV1/FVC in chronic spinal cord injury. *Arch Phys Med Rehabil*. 2006;87:1327-1333.
- Baydur A, Adkins RH, Milic-Emili J. Lung mechanics in individuals with spinal cord injury: Effects of injury level and posture. *J Appl Phys*. 2001;90:405-411.
- Fugl-Meyer A. Effects of respiratory muscle paralysis in tetraplegic and paraplegic patients. *Scand J Rehabil Med*. 1971;3:141-150.
- Watson PJ, Hixon TJ. Effects of abdominal trussing on breathing and speech in men with cervical spinal cord injury. *J Speech Lang Hear Res*. 2001;44:751-762.
- Hixon TJ, Putnam AHB. Voice disorders in relation to respiratory kinematics. *Sem Speech Lang*. 1983;4(3):217-231.
- Hixon TJ, Putnam AHB, Sharp J. Speech production with flaccid paralysis of the rib cage, diaphragm, and abdomen. *J Speech Hear Dis*. 1983;48:315-327.
- MacBean N. *An Examination of Speech Production on Individuals Post Cervical Spinal Cord Injury*. St Lucia, Qld: University of Queensland; 2007.
- MacBean N, Ward E, Murdoch B, Cahill L. Characteristics of speech following cervical spinal cord injury. *J Med Speech Lang Pathol*. 2006;14(3):167-184.
- Nygren-Bonnier M, Normi LL, Klefbeck B, Biguet G. Experiences of decreased lung function in people with cervical spinal cord injury. *Disabil Rehabil*. 2011;33(6):530-536.
- Duffy J. *Motor Speech Disorders*. St. Louis, MO: Mosby-Year Book; 1995.
- Ward E, Solley M. Traumatic spinal cord injury. In: Ward EC, Morgan A, eds. *Dysphagia PostTrauma*. San Diego: Plural Publishing; 2009:67-150.
- Rutchik A, Weissman A, Almenoff P, Spungen A M, Bauman WA, Grimm D. Resistive inspiratory muscle training in subjects with chronic cervical spinal cord injury. *Arch Phys Med Rehabil*. 1998;79(3):293-297.
- Gross D, Ladd H, Riley E, Macklem P, Grassino A. The effect of training on strength and endurance of the diaphragm in quadriplegia. *Am J Med*. 1980;68(1):27-35.
- Clough P. Glossopharyngeal breathing: Its application with a traumatic quadriplegic patient. *Arch Phys Med Rehabil*. 1983;64:384-385.
- Johansson KM, Nygren-Bonnier M, Klefbeck B, Schalling E. Effects of glossopharyngeal breathing on voice in cervical spinal cord injuries. *Int J Ther Rehabil*. 2011;18(9):501-512.
- Bach J, Alba A. Noninvasive options for ventilatory support for the traumatic high level quadriplegic patient. *Chest*. 1990;98:613-619.
- Hoit JD, Banzett RB, Brown R. Binding the abdomen can improve speech in men with phrenic nerve pacers. *Am J Speech Lang Pathol*. 2002;11:71-76.
- McCool F, Pichurko B, Slutsky A, Sarkarati M, Rossier A, Brown R. Changes in lung volume and rib cage configuration with abdominal binding in quadriplegia. *J Appl Phys*. 1986;60(4):1198-1202.
- Goldman J, Rose L, Williams S, Silver J, Denison D. Effect of an ABs on breathing in tetraplegic patients. *Thorax*. 1986;41:940-945.
- Wadsworth BM, Haines TP, Cornwell PL, Rodwell TL, Paratz JD. An AB improves lung volumes and voice in people with tetraplegic spinal cord injury. *Arch Phys Med Rehabil*. 2012;93(12):2189-2197.
- Hart N, Laffont I, Sota APD, et al. Respiratory effects of combined truncal and abdominal support in patients with spinal cord injury. *Arch Phys Med Rehabil*. 2005;86(7):1447-1451.
- Boaventura CM, Gastaldi AC, Silveira JM, Santos PR, Guimaraes RC, De Lima LC Effect of an an AB on the efficacy of respiratory muscles in seated and supine tetraplegic patients. *Physiotherapy*. 2003;89(5):290-295.
- Marino R, Barros T, Biering-Sorensen F, et al. ASIA Neurological Standards Committee 2002. International standards for neurological classification of spinal cord injury. *J Spinal Cord Med*. 2003;26(S1):S50-56.
- Ouanjer Ph H, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC. Lung volumes and forced ventilatory flows. *Eur Respir J*. 1993;6(Suppl 16):5-40.
- Kelley A, Garshick E, Gross ER, Lieberman SL, Tun CG, Brown R. Spirometry testing standards spinal cord injury. *Chest*. 2003;123:725-730.
- Fairbanks, G. *Voice and Articulation Drillbook*. New York: Harper and Row; 1960.

35. Kerk JK, Clifford PS, Snyder AC, et al. Effect of an abdominal binder during wheelchair exercise. *Med Sci Sport Exerc.* 1995;27:913-919.
36. Computerised speech laboratory [computer program]. Montvale, NJ: KayPENTAX.
37. Kent R, Vorperian H, Duffy J. Reliability of the multi-dimensional voice program for the analysis of voice samples in participants with dysarthria. *Am J Speech Lang Pathol.* 1999;8:129-136.
38. Dejonckere PH, Lebacqz J. Acoustic, perceptual, aerodynamic and anatomical correlation in voice pathology. *J Otorhinolaryngol Relat Spec.* 1996;58:326-332.
39. Hirano M. *Examination of Voice*. New York: Springer; 1981.
40. International Telecommunication Union. Series P: Telephone transmission quality. Methods for objective and subjective assessment of quality. Series P-800. 1996. Updated July 31, 2006. Retrieved from <http://www.itu.int/rec/T-REC-P.800-199608-I/en>
41. Bodin P, Fagevik Olsen M, Bake B, Kreuter M. Effects of abdominal binding on breathing patterns during breathing exercises in persons with tetraplegia. *Spinal Cord.* 2005;43:117-122.
42. DeTroyer A. Mechanical role of the abdominal muscles in relation to posture. *Respir Physiol.* 1983;53(3):341-353.